Argonne's Computing and Communications Infrastructure Futures Laboratory
Designing the Future

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Abstract

The Futures Lab was founded within the Mathematics and Computer Science Division of Argonne National Laboratory in the fall of 1994. The goal of the lab is develop new technology and systems to support collaborative science. In order to meet this goal, the lab is organized around three research areas: advanced networking, multimedia, and virtual environments.

The Argonne Computing and Communications Infrastructure Futures Laboratory (Futures Lab) was created in 1994 to explore, develop, and prototype next-generation computing and communications infrastructure systems. An important goal of the Futures Lab project is to understand how to incorporate advanced display and media server systems into scientific computing environments. The objective is to create new collaborative environment technologies that combine advanced networking, virtual space technology, and high-end virtual environments to enable the construction of virtual teams for scientific research.

We believe that digital media, immersive displays, and networked collaborative spaces are critical elements of future computing environments and will be in common use by the end of the decade. We hope that our efforts will provide new capabilities to scientific computing systems and will accelerate development of virtual organizations to conduct experimental, computational, and theoretical science.

Our efforts are largely focused on technology development and integration with selected applications projects used to demonstrate the new technology. We are interested in driving large-scale supercomputer systems architecture toward more balanced (and human-oriented) systems that can support a variety of human interfaces and media systems. We believe that large-scale parallel computing and immersive technology are naturally complementary; hence, we are devoting considerable effort to develop improved mechanisms for linking parallel supercomputers and immersive displays. We also believe that the collaborative environments we envision are logical extensions of the classic Internet and that these new systems will enable diverse sets of people to collaborate on important computationally driven problems in science and engineering.

The Futures Lab project will be successful if, in the future, widespread groups are enabled to collaborate in the solution of large-scale scientific and engineering problems, such as the development of nanotechnology, advanced integrated earth systems modeling, new environmental technology, and advanced industrial design.

1 Multimedia and Collaborative Space Project

The Futures Lab at Argonne operates a multimedia lab for conducting multimedia experiments and integration experiments with massively parallel computers. The principal resource this laboratory provides is access to a 12-node IBM SP2 parallel computer that has been configured with audio and video hardware and a large amount of disk space to enable the prototyping of parallel multimedia servers [5]. The laboratory also contains three PowerPC workstations with audio and video support. In addition to the computers, the multimedia lab has a variety of video cameras, microphones and speakers, audio amplifiers, scan converters, active whiteboards, video and audio switches and mixers, large screen monitors, Hi8 and VHS editing facilities, and state-of-the-art advanced networking.

Three projects are under way: LabSpace, Voyager, and the National High Performance Computing and Communications Software Exchange. As part of a joint project with IBM, the group is also developing scalable multimedia servers and is studying the integration of multimedia technologies with high-performance parallel computers.

1.1 LabSpace

The goal of the LabSpace project; a joint project with Northeastern University; is to develop tools that enable the construction of collaborative environments that will provide location independence for groups of researchers. Users of LabSpace tools will have access to remote scientific instruments and collaborative tools, as well as to meeting rooms, private offices, and interaction areas – all via virtual networked spaces. These networked spaces (called electronic labs, or elabs) will be based on technology derived from multiuser virtual environment

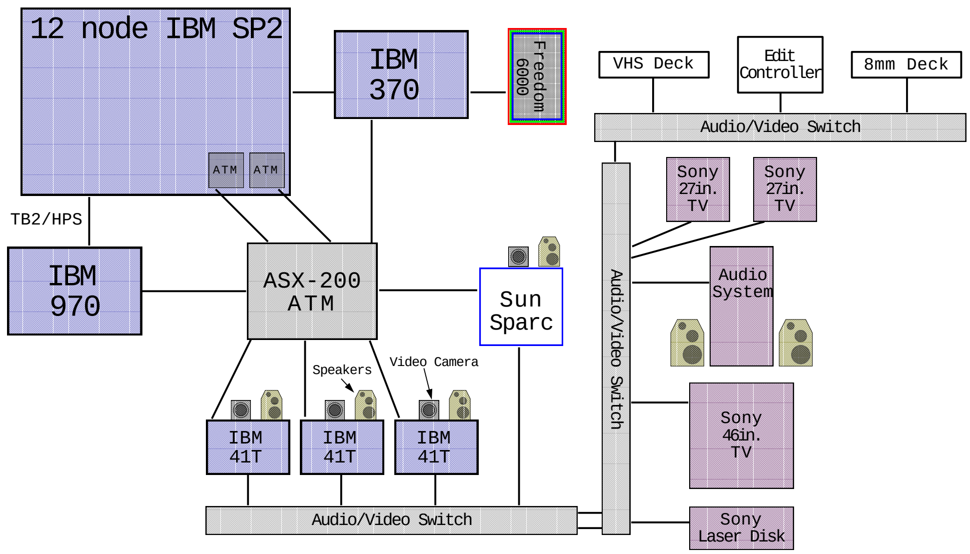

Figure 1: Futures Lab Multimedia Setup

technology developed by Xerox PARC's MOO [2] project. The tools will be built with Internet standard protocols and data formats.

1.1.1 LabSpace Objectives

The LabSpace project's primary objective is to create virtual electronic laboratories that will allow distributed scientific research groups to collaborate naturally and effectively. The LabSpace project's goal can be reached by satisfying a number of essential objectives.

- **Persistence**

  Casual and ongoing interactions are as much a part of collaboration as preplanned meetings. In order to make such interactions possible, the elab must always be available. Therefore, the elab will promote the "cafe" style of interaction rather than the "phone call" model. Users will be able to leave an experiment in progress and come by later to check on its status. This persistence is a basic design goal of the elab server.

- **History**

  Existing multiuser virtual environments provide very little history mechanism. It is critical for scientists to be able to record and play back parts of a meeting or of a scientific experiment.

- **Existing Tools**

It is important that existing tools be used in the LabSpace project, not only to leverage existing technology and minimize duplicated work, but also to allow scientists to use the workstation environment with which they are already comfortable.

- **Network Independence**

  LabSpace is being built on existing Internet standards, using TCP/IP as a basic network protocol. However, the network level is being built as an abstraction, allowing LabSpace to be moved to other network protocols.

  In addition, some parts of LabSpace are benefiting greatly from the presence of multicast networking capability, but will be able to function without it should the need arise.

- **Security**

  Secure data is a requirement in many environments. The elab server itself is implementing a comprehensive permission scheme, allowing only authorized users to connect and interact with objects. In addition, the network transmissions must be secure, a requirement that is factored into the initial design.

- **Flexibility**

  The LabSpace design is explicitly modular, allowing for new interaction mechanisms to be added at any time. For example, should a group wish to add a CAVE interface to the set of tools they use to collaborate, it will be necessary only to write the modules that send, receive, and display the CAVE data. No modification to other aspects of the LabSpace architecture will be necessary.

- **Scalability**

  In general, the scalability of the collaboration is more likely to be limited by human constraints rather than technical restrictions.

As these objectives are reached, LabSpace will provide an environment that promotes interaction, collaboration, and extensibility. The benefits to the users are clear. They will be able to maintain contact with their fellow researchers regardless of their location. They will be able to set an experiment in motion within an elab, and return at a later date to check on the progress. They will have a permanent and natural interface to their scientific instruments and to information archives. The tools that they need to carry out such interactions will be united under a common interface, as natural and as powerful as the World Wide Web browser upon which it is based. As technical limitations are removed, the collaborations will be more productive than before, with less stress on the individuals involved.

1.1.2 Technical Plan

The LabSpace technical architecture consists of the following:

- A powerful and intuitive virtual environment, which creates a permanent electronic laboratory on the network, allowing one to interact with other people and with objects in natural ways.
- Navigation and browsing tools, which help one to locate collaborative resources on the Internet.
- High-capacity data archiving mechanisms, which record and index significant events in the history of a collaboration.
- Interfaces to advanced scientific instruments, which are the focus of much interaction.
- Modules that take advantage of the capabilities of modern workstations, utilizing audio, video, or any other interaction tool necessary to support collaboration.
- A scalable and flexible interface to the networks of today and tomorrow.

1.2 Voyager Server Project

Complementing the LabSpace effort is the Voyager project. The initial goal of Voyager is to develop the next-generation hypermedia server architecture that will enable the construction and rapid deployment of tools for building virtual organizations [4]. Ultimately, Voyager is intended to replace the types of servers currently used for supporting collaborative environments (e.g., ftp servers, web servers, document servers). In addition, Voyager will provide an extensible environment for making audio, video, and other stream-oriented recordings available to others on the network. Each user in a virtual organization will can Voyager to publish information for the rest of the organization's users. Voyager will also support the construction of virtual spaces that can be linked to allow others to visit one's "virtual office" to talk or collaborate. Voyager is being designed to be deployed both at the desktop level and as a large, scalable server for high-performance media serving applications.

1.3 National HPCC Software Exchange

The National High Performance Computing and Communications Software Exchange (NHSE) is a joint effort by the National Science Foundation Center for Research on Parallel Computation (Argonne, Caltech, Los Alamos, Rice, Syracuse, and Tennessee) to provide easy access to HPCC-related software, documents, and data.

Argonne, as part of the NHSE project, is building tools for exploring advanced Web resource management technologies. These tools will support searching and gathering Web pages, compression, indexing, transaction monitoring, parallel search, and a rich language environment for developing agents.

1.3.1 Modular Web Robot

One of the tools is a modular programmable Web robot that is designed to efficiently cache web pages on a local server based on programmable starting locations, keywords, file types, and other search criteria. This Web robot is designed to be run in parallel to allow high-performance gathering of Web pages. Its modular design enables it to be rapidly modified for experimental purposes. This robot has collected data on thousands of Web sites. The robot will be used within the NHSE project to provide the raw Web pages needed for testing indexing, queries, and agents.

1.3.2 Parallel Web Indexing Engine

The NHSE project is also developing a parallel indexing system for rapidly indexing Web pages on parallel systems and for providing rapid regular expression-based parallel searches of Web page caches, such as those generated by a Web robot. In addition, extensions to the query system are being added specifically to allow the discovery of "software" in the midst of other Web information, thus supporting the ability to search for data that contains software (source files, binaries, tar files, makefiles, etc.) across the Web. This Web indexing engine is designed to be scalable to millions of URLs.

1.3.3 Domain Name Server / Geographical Database and Mapping Software

The third element of Argonne's NHSE project is the development of a database to support mapping Internet site domain names to geographical places for display on a variety of GIS systems. This database provides the ability to map Web usage log data to geographical coordinates, thereby allowing users to visualize the geographical distribution of requests to Web servers. The mapping software provides various views of the United States and other geographical areas and provides the background for displaying the locations of server connections and downloads. This tool provides the NHSE contributor or maintainer an instant overview of the number and location of sites that have downloaded NHSE software and data.

1.3.4 Autonomous Agents

Several types of search agents are also being developed. One agent is designed to build up a comprehensive database of network available information based on a keyword list and to provide the user with daily updates regarding changes to this database. Another agent is designed to monitor a set of Web sites and to determine significant changes in the Web structures for these sites.

2 Virtual Environments Project

The purpose of the virtual environments project is to develop advanced visualization tools and environments to increase scientists' productivity and to enhance scientific understanding of the results of large-scale applications being developed on parallel supercomputers. In particular, the tools under development exploit advances in virtual environments, networking, and massively parallel processing technology.

The recent development of immersive virtual environments such as the Cave Automatic Virtual Environment (CAVE^{TM})[1] has provided an exciting new means for scientists to explore the behavior of multidimensional physical and biological phenomena. However, further development is vital in order to address the requirements imposed by problems being solved on large-scale parallel computers.

A CAVE was installed at Argonne during mid-1994. Argonne's CAVE, as part of the Futures Lab, is intended primarily as a research vehicle for understanding the computer science aspects of advanced visualization techniques coupled with high-performance computing and multimedia applications.

A variety of different applications have been developed in Argonne's CAVE since it was installed:

- Visualization of Casting Process in Foundries: Pouring of a fluidity spiral used to measure the distance metal can flow in a channel before being stopped by solidification.

- Interactive Adaptive Mesh Refinement: Demonstration of a fundamentally new way in which scientists can control mesh density from within an immersive visualization environment.

- Interactive Finite Element Analysis of Grinding Surfaces: Real-time simulation of a grinding process (see Figure 2).

- Interactive Molecular Modeling: Docking of a drug molecule to its molecular receptor by using real-time interactive molecular modeling and molecular dynamics simulations (see Figure 2).

- Ion Visualization: Visualization of shell structures for large-scale ion clusters (see Figure 2).

[1] The CAVE and ImmersaDesk are registered trademarks of the Board of Trustees of the University of Illinois.

- Volume Visualization: Data display of three-dimensional images of medical and astrophysical using standard volume visualization techniques.
- Mesoscale Weather Model Visualization: Visualization of data generated by a large supercomputer weather model.
- Molecular Modeling Visualization: Visualization of atom-to-atom interactions and the processor mappings.
- Nuclear Reactor Walkthrough: Modeling of experimental breeder reactor and its fuel-handling sequence to prove the concept of virtual control systems.
- Visualization of Accelerator Magnets: Simulation of wigglers, a special array of magnets used in Argonne's Advanced Photon Source (see Figure 2).
- Subsurface Visualization: Visualization of contaminant levels in a valley in southern Germany.

2.1 CAVE

The CAVE is a virtual reality environment originally developed at the Electronic Visualization Laboratory (EVL) at the University of Illinois at Chicago and now an active research project at EVL, Argonne National Laboratory, and the National Center for Supercomputing Applications [1]. In its current implementation, the CAVE uses three projectors, displaying computer images on two walls and the floor of a ten-foot cube. Images are rear projected onto translucent screens. A three-dimensional image is achieved by displaying slightly different views of the scene for the right and left eye. The final hardware required to support the illusion is stereo shutter glasses that allow only one eye to see one of the displayed images at a time. The user's position and orientation are tracked by an electromagnetic tracking system, thereby allowing the environment to be rendered in correct viewer-centered perspective. The user is able to manipulate objects and navigate within the CAVE by using a wand, a three-dimensional analog of the mouse of current computer workstations. The size of the CAVE is approximately 10' x 10' x 10', large enough for several people to be in the CAVE and to share the experience. While only one user is tracked and has the correct perspective, experience has shown that other users in the CAVE wearing stereo glasses see a satisfactory image.

CAVE simulators are available to anyone having access to a Silicon Graphics workstation. A recent low-cost addition to the CAVE family of VR devices is the ImmersaDesk$^{\mathrm{TM}}$under development at EVL, which is a one-wall CAVE the size of a standard drafting table. Argonne will be investigating an ImmersaDesk-type technology later in 1995.

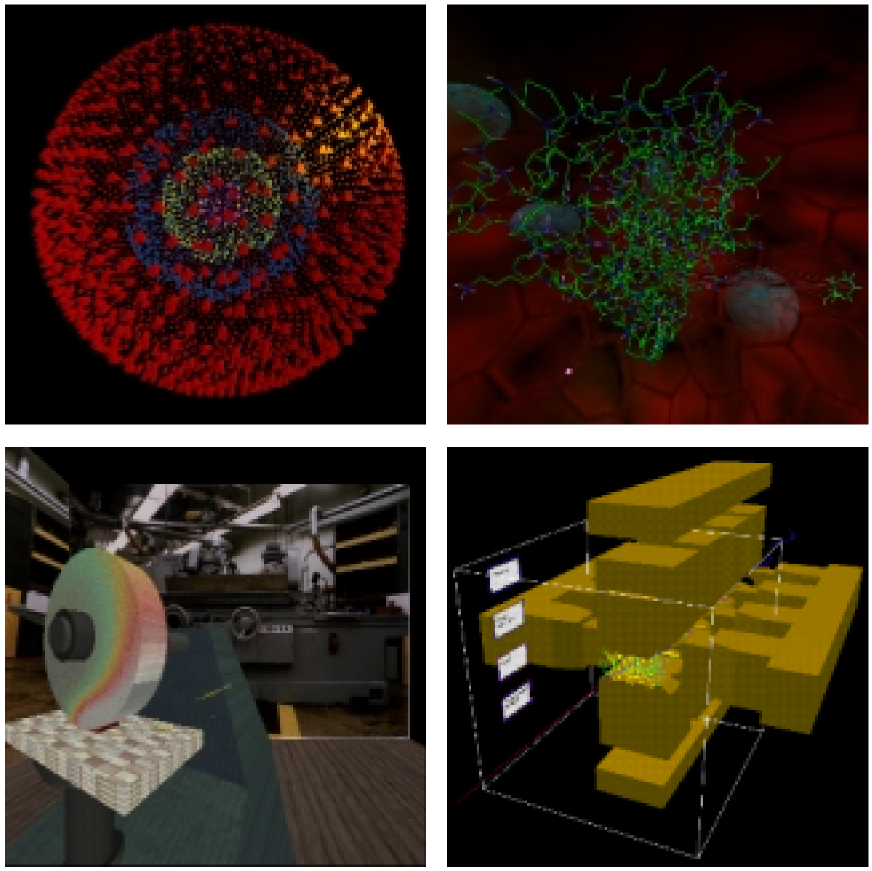

Figure 2: Ion Visualization, Molecular Modeling, Finite Element, and APS magnet

2.2 Current Projects

The virtual environments project within the Futures Lab is addressing four areas: CAVE-to-CAVE Library, applications and demonstrations, software environment and performance analysis, and archiving and experience recording.

2.2.1 CAVE-to-CAVE Library

The virtual environments project is devoting significant effort on research in shared virtual environments [3]. This includes the development of a CAVE-to-CAVE library. The library encapsulates CAVE-to-CAVE methods, mechanisms, and concepts. Considerable effort is being spent developing models to support effective CAVE-to-CAVE communication. In order for CAVE-to-CAVE

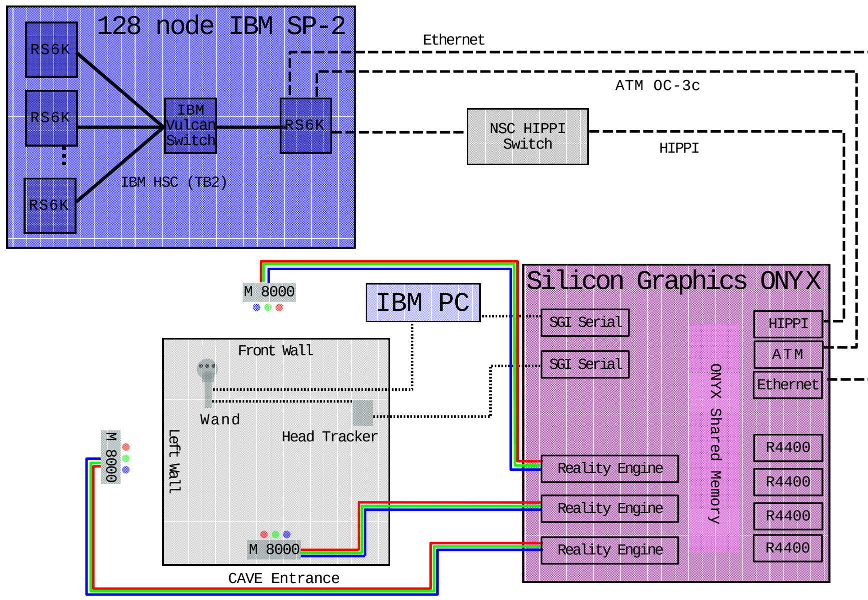

Figure 3: Futures Lab Virtual Environment Setup

applications to scale beyond two CAVEs, effective use of the Internet protocol multicast methods must be employed. Studies are needed to determine the amount of data that can be effectively multicast. In addition, experiments are planned to investigate how the RTP (Real Time Protocol) can be used to support CAVE-to-CAVE interactions.

Finally, plans are under way to integrate the CAVE-to-CAVE framework with that of the LabSpace event managers. (LabSpace is designed to scale to support CAVEs as user interfaces.) This work includes experiments to explore the integration of the LabSpace event models to support CAVEs as LabSpace interactive clients.

2.2.2 Applications and Demonstrations

Applications are used to validate approaches to software, but they also are an important way to explore the impact of virtual environment interfaces to scientific applications. Applications and demonstrations are a central strategy of the Futures Lab research program. The Futures Lab is developing applications to be demonstrated as part of the Information Wide Area Year at Supercomputing 95. These applications include an artificial life demonstration, remote engineering using CAVE to CAVE technology, telerobotics, and visualization of protein-drug interactions.

Development of new visualization paradigms for ImmersaDesk-like systems is also planned. Because of their portability, ImmersaDesks offer new opportunities a rich area for exploration of virtual environments. The virtual environments project will explore new ways to use such single-wall environments for merging three-dimensional graphics, video, text, and sound for supporting collaborative work.

2.2.3 Software Environment and Performance Analysis

The Electronic Visualization Laboratory at the University of Illinois at Chicago, originally developed the CAVE library, maintain the core code for the library. The virtual environment project at Argonne is modifying the library to explore new issues. The virtual environment project is also interested in experiments that compare real three-dimensional objects with simulated objects objects. The goal of these experiments is to improve the rendering and interactions in the CAVE. Initial experiments will start with relatively simple structures. A variety of rendering and perspective models will be used. The results will be incorporated into the next-generation CAVE library.

The group is also looking into improvement of resolution and tracking control. Experiments will be conducted to determine ways to improve the CAVE's resolution from current 1024 x 768 pixels per wall to 1024 x 1280 and later to 1024 x 1920 pixels. These experiments will include evaluating of new types of projectors, interlacing multiple projectors, and using adaptive resolution techniques.

Another major emphasis in the area of library support is performance analysis of distributed CAVE applications. As more CAVE applications are using high-performance computing backends, it is becoming increasingly important to understand the details of network and systems performance on the interactive effectiveness of the CAVE. Distributed CAVE applications are being instrumented, and the performance data will be analyzed to improve interactive responsiveness [6].

An important project is the development of a generic CAVE library that supports additional hardware platforms beyond that of Silicon Graphics. The first effort will be a Freedom 6000-based CAVE library. The CAVE library will be ported to the IBM hardware, and a series of experiments will be undertaken to explore the use of Freedom 6000s to drive CAVE-type displays.

2.2.4 Archiving and Experience Recording

The fourth area of major focus to the virtual environments project is that of recording and playback of CAVE sessions. This includes the recording, playback, and compression of stereo images; multiresolution compression; stereo compression; and a variety of motion compensation and hybrid algorithms. Recording experiments will also be done by capturing and playback of event streams. The goal is to provide the means to archive CAVE interactions. Plans also include demonstrating the recording and playback of limited-duration CAVE experiences. These recordings will be used to understand the nature of immersive multimedia streams. Experiments will be conducted to demonstrate the portability of these recordings by playing them at a remote CAVE installation.

3 Advanced Networking

The Futures Lab advanced networking technology project is exploring the use of wide-area ATM networks to support multimedia and virtual environments research. Particular focus is on interactive video, distributed applications, and remote computations for interactive virtual environments and scientific visualization. The group is also prototyping experimental LANs to support virtual reality demonstrations, large-screen projection system demonstrations, and communications for video servers. Finally the group is experimenting with the use of high-speed wireless LANs.

4 Conclusions

The Futures Lab and its associated research projects are a new research focus for the Mathematics and Computer Science Division at Argonne. Our approach is both interdisciplinary and collaborative. Two primary projects—the multimedia and collaborative space project and the virtual environments project—are under way, both supported by activities in advanced networking. Our efforts have already begun to influence how we and our colleagues are approaching large-scale computational problems and how we are thinking about future research collaborations. We believe that these projects will provide a rich set of new ideas and sources for creative expression that will greatly strengthen our work in scientific computing and computational science.

We are interesting in working with other groups that have common interests, and we welcome visitors and electronic communication.

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References

[1] C. Cruz-Neira, D. J. Sandin, and T. A. DeFanti. Surround-screen projection-based virtual reality: The design and implementation of the CAVE. In *ACM SIGGRAPH '93 Proceedings*, pages 135–142. SIGGRAPH, ACM SIGGRAPH, 1993.

[2] P. Curtis. Mudding: Social phenomena in text-based virtual realities, 1992. presented at Directions and Implications of Advanced Computing, Boston, `ftp://parcftp.xerox.com/pub/MOO/papers/DIAC92.ps`.

[3] T. L. Disz, M. E. Papka, M. Pellegrino, and R. Stevens. Sharing visualization experiences among remote virtual environments. In *International Workshop on High Performance Computing for Computer Graphics and Visualization*. Springer-Verlag, 1995.

[4] R. Stevens, T. Disz, R. Olson, M. E. Papka, and R. Evard. Voyager: A next generation hypermedia server to support the construction of virtual organizations, 1995. Grant Proposal, Submitted to DOE 1995.

[5] R. Stevens and R. Evard. Distributed collaboratory experimental environments initiative LabSpace: A national electronic laboratory infrastructure, 1994. Grant Proposal, Submitted to DOE 1994.

[6] V. Taylor, R. Stevens, and T. Canfield. Performance models of interactive, immersive visualization for scientific applications. In *International Workshop on High Performance Computing for Computer Graphics and Visualization*. Springer-Verlag, 1995.